Technical Memorandum No. 33-41

A PRELIMINARY INVESTIGATION OF SOME OF THE MAJOR SYSTEMS INTEGRATION CONSIDERATIONS FOR NUCLEAR ELECTRIC PROPULSION SPACECRAFT

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I. INTRODUCTION

The Integration Group of the Advanced Propulsion Engineering Section has performed a series of preliminary studies as an initial step toward determining the optimum engineering relationship of the major assemblies of the advanced propulsion system and the assemblies of others systems which together form a complete spacecraft. In the course of these studies consideration was given to the various mission, booster, and ground handling constraints as well as to the limitation of present and anticipated hardware techniques.

This Memorandum summarizes some of the significant points of these early integration studies.

II. CONFIGURATION STUDIES

A. General Background

In order to define the potential areas of concern in the development of nuclear electric propelled spacecraft from an integration standpoint, a series of conceptual configuration studies have been undertaken. These studies represent a continuation of the work initiated by the Electric Propulsion Integration Committee and consider in a preliminary manner all of the major systems associated with a typical nuclear electric propulsion spacecraft; that is, the energy source, the power generation equipment, the power conditioning system, the thrust unit, propellant feed system, the guidance and control system, structure and thermal control, telecommunications, instrumentation, and the scientific payload.

As a result of these studies several basic spacecraft models have been formulated from which the major integration problems may be ascertained and studied. These models are all based on the utilization of a SNAP-8 type nuclear electric power system driving an ion engine, and are considered to be boosted into an Earth orbit by an Atlas-Centaur booster prior to initiation of the ion engine operation. A further constraint of minimum change to the booster vehicle was also assumed for these studies.

B. Specific Inputs

Looking in more detail at some of the typical subsystem and mission inputs which have been considered in these preliminary studies, one finds that the first and perhaps the most demanding item from the standpoint of its effect upon other equipment on board the spacecraft is the energy source, i.e., the nuclear reactor. Figure 1 shows a cutaway view of a typical first generation spacecraft power reactor, the SNAP-8 reactor. It is approximately 21 in. long by 18 in. in diameter. It should be located in an area relatively free of structure and other equipment in order to allow for radiation cooling of its control drums, reduce the influence of the spacecraft structure on the controllability of the reactor, and reduce back scattered nuclear radiation. The reactor, of course, is an intense source of nuclear radiation and must be placed away from the more sensitive equipment on board the craft.

The second item of interest is the power conversion system. Figure 2 shows a typical turboelectric conversion unit. This is the 30 kwe SNAP-8 assembly. It is approximately 43 in. long by 29 in. high not including the radiator panels. The conversion system in operation runs at high temperatures and is the source of some nuclear radiation. For these studies it was assumed that two counter rotating conversion units of the SNAP-8 type sharing a common boiler and designed to deliver a total of 60 to 70 kwe were utilized.

The other major propulsion components considered in the studies are the thrust unit delivering about 0.4 lb total thrust and composed of a series of small modular units, and a zero "g," elevated temperature, cesium propellant tank and feed system. The thrust unit was estimated to have an area of about 13 sq ft, while the propellant tank, for a typical Mars orbiter mission, was selected at 35 cu ft.

The electronic components consisting of the guidance and control elements, telecommunication and instrumentation units, and the scientific payload, all of which are radiation and temperature sensitive, were grouped together and located in an area shielded from the reactor. A volume of 30 cu ft was estimated for this equipment. Some scientific instruments which might require lower background radiation levels than the normal electronic equipment will necessitate additional secondary shielding or extreme distance separation from the main body of the spacecraft.

The attainment of tolerable radiation levels for the normal electronic packages requires the installation of a primary radiation shield of a material such as lithium hydride, so that the necessary radiation attenuation can be accomplished in a reasonable distance. This shield must be positioned such that it can radiate to space the heat associated with the nuclear radiation absorption by the shield material. A radiation tolerance for the electronic components of $10^{13} n/cm^2$ for fast neutrons and 10^9 ergs/gm(c) for gammas was assumed for the shield estimates.

Additional provisions were made for a 10-ft-diameter steerable communication antenna and various guidance elements to track the Sun, stars, and a target planet. Care was taken to avoid locating the antenna where it would have to communicate through the ion engine beam. This latter requirement is not particularly easy in view of the manner in which the thrust vector changes direction during a typical electric propulsion spacecraft trajectory.

The last major item to be mentioned, the waste heat radiators, provides one of the more interesting challenges from a configuration standpoint. Approximately 1200 sq ft of radiating area for the rejection of waste heat from the power conversion system, in these particular studies, must be packaged compactly for the boost flight and extended in a reliable fashion for the ion engine portion of the flight. The radiator temperature during normal operation will run between 600 and 700°F.

Consideration must also be given to the requirement for radiative cooling of the electronic components and power conditioning equipment such as transformers and rectifiers. It was found in these studies that an additional radiating surface of approximately 100 sq ft at 200°F. will be required. The transfer of waste heat from high density heat producers such as the transformers probably will necessitate the use of an active cooling loop.

As a general rule, it has been noted that those items which are the hottest from a nuclear radiation standpoint are also the hottest from the gross thermal viewpoint and thus can be grouped together in a logical arrangement at one end of the spacecraft. Likewise, the thermally sensitive equipment, primarily the electronic units, are also radiation sensitive. These are grouped at the maximum feasible distance from the hot components.

C. Typical Configurations

Some of the representative types of configurations which resulted from consideration of the aforementioned inputs and constaints are shown on the following pages. It should be noted that these configurations at this point are based on a gross investigation of the integration aspects only and that more thorough studies will be required before one can choose an optimum design; for example, the location of secondary radiating surfaces are not detailed in these configurations.

Figure 3 shows an early configuration based on a flat primary radiator concept. Note the following major aspects of this configuration:

1. The direction of flight is along the longitudinal axis.
2. The radiator panels during boost are wrapped around the spacecraft.
3. The ion engine is located at the aft end of the spacecraft.
4. The reactor, shield and conversion system are located in the middle.
5. The payload is located at the forward end.
6. The propellant tank is located between the payload and the conversion units.
7. A shroud fits over the entire spacecraft during boost flight.

One of the potential problem areas associated with this design results from the effects of the poor dynamic characteristics of the flexible radiator panels upon the operation of the attitude control system. It also appears that the look angles for the guidance sensors and the communication antenna are not too favorable with this arrangement.

Figure 4 shows an approach where an attempt was made to make the primary radiator more rigid through the use of a cylindrical shape. Note the following major aspects of this design:

1. The direction of flight is perpendicular to the longitudinal axis.
2. The telescoping radiator assembly forms a section of the spacecraft shroud during boost flight and is extended following boost.
3. The ion engine is located on the side of the spacecraft and thrusts through the center of mass.
4. The reactor, shield, and conversion system are located at one end and the payload at the opposite end.

Unfortunately, this radiator configuration allows for use of only the outer surface for radiating to space. In order to maintain a reasonable length during boost, several telescoping sections would be required which could result in a complex extension mechanism.

It should be noted that here an attempt has been made to have the radiator serve a double function; that is, it forms the lower portion of the shroud during the boost flight as well as performing its normal radiating function during the ion engine operation. This principle of dual functions may help to make the need for large radiator surfaces more tolerable.

Figure 5 shows an attempt to utilize both sides of a cylindrical primary radiator surface. Although there is some loss of radiation efficiency from the concave side, the over-all increase in radiator size over a flat surface radiator does not appear to be great. In an attempt to keep the spacecraft as short as possible in the boost arrangement, it was considered that the radiator panels might fold down over the upper booster stage.

Note the following major points:

1. The direction of flight is upwards in the figure.
2. The ion engine is located on the bottom.

Figure 6 illustrates a more recently investigated concept. This configuration is an extension of the previously discussed design. Note the following aspects of this configuration:

1. The direction of flight is to the left in the figure.
2. The ion engine and propellant tank are located in the middle of the spacecraft.
3. The reactor and shield are located on the bottom and the conversion units in the middle (within the toroidal propellant tank).
4. The payload and steerable antenna are on top.
5. The radiator panels fold up around the spacecraft forming the shroud during boost flight.
6. Attitude stabilization and guidance might be accomplished by differential thrust modulation of groups of thrust units.

With this configuration, the look angles for the guidance sensors and the antenna appear favorable for flights both in the plane of the ecliptic and at various angles out of the plane of the ecliptic. The radiator panels are oriented to present a relatively small surface to the direction of the Sun.

The over-all height of this craft including the antenna is about 34 ft; the width from one radiator tip to another is about 55 ft. In the boost arrangement the spacecraft is about 24 ft tall. The previous configurations have similar dimensions.

D. Future Spacecraft Trends

Later generations of nuclear electric propulsion spacecraft, up to 1 mw, have also been studied briefly. It appears that the basic spacecraft configuration which is selected for the first generation craft will probably lead directly to later generation spacecraft. This is due to the fact that the future anticipated boosters (perhaps advanced Centaur or Saturns) will impose similar size and boost phase constraints upon the spacecraft. It is also anticipated that the mission constraints will be similar; i. e., look angles, etc.

In general, later missions will be more energetic necessitating higher power levels, longer life, and increased propellant loads. It is expected that the power level reactors and conversion systems will not grow significantly in size due to the higher operating temperatures and resulting higher efficiencies. The heat rejection radiators for both the power conversion system and electronic equipment cooling will probably grow in size, however. The thrust units will shrink in size at the higher required specific impulses. The propellant tanks will obviously increase in volume. Thicker radiation shields will be required at the higher reactor power levels and longer operating lifetimes. Improved tolerance of components to radiation may offset this latter point somewhat.

Over-all spacecraft dimensions will grow, but it is difficult to predict the actual size as this is strongly dependent upon the required heat rejection radiator areas. These areas in turn are dependent upon operating temperatures and system efficiencies. Hopefully, higher temperatures and efficiencies will allow for spacecraft designs which will be similar in size to those previously stated.

III. REQUIRED DEVELOPMENT EFFORT

During the course of investigating the various first-generation nuclear electric propulsion spacecraft configurations, a preliminary recognition of some of the major problem areas which will be associated with the development of the spacecraft was obtained. These areas will require particular effort if a reliable flight system is to be realized. It should be noted that many of these points, which will be discussed briefly, will require continuing effort in support of later generations of electric spacecraft as well as the first generation, and that some of the areas are common to those already under investigation in support of existing non-nuclear spacecraft such as Ranger and Mariner.

Probably the most important and most difficult task will be the development of the necessary system reliability for long life. Lifetimes of a year to two years are required. Coupled with the goal of achieving long life is the problem of developing accelerated ground test techniques for reliability demonstrations in reasonable time periods.

Advanced radiator designs involving the use of high emissivity coatings, improved micrometeorite protection, higher operating temperatures, and improved boost phase packaging must be pursued. This area of development is particularly important when one realizes that the radiator dimensions, perhaps more than any other component characteristic, determine the over-all spacecraft size.

The nuclear radiation tolerance of equipment, particularly the electronic devices, must be increased both to improve reliability and to reduce shield weights. The present efforts in support of the Aircraft Nuclear Propulsion, Rover, and Pluto programs already provide a foundation for this endeavor.

In a similar manner, development effort will be required to raise the temperature tolerance of electronic devices to higher levels.

Additional knowledge of the space environment upon materials must be determined, for example, the effect of long vacuum soak periods upon lubricants, etc.

Effort must be devoted to developing reliable zero "g" propellant feed systems. Effort must also be spent in studying other zero "g" problems such as phase separation in condensing radiators.

Unique handling and checkout methods must be developed for the production and flight testing of the electric propulsion equipment, particularly, the reactor, conversion units and ion engine assemblies. The early flight of the SNAP 2 system may aid in developing some of the nuclear handling methods, while an ion engine test flight on a Scout vehicle will aid in the thrust unit and propellant feed areas.

New flight and ground instrumentation techniques must be developed to provide for the adequate measurement of extremely low thrust and flow rate levels. Thrust levels less than 1 lb and flow rates less than 0.00015 lb/sec must be measured.

And finally, effort must be directed toward improving the over-all efficiency of the electric power production, power conditioning and thrust producing equipment to ensure that adequate performance is achieved to propel useful payload weights.

Power production specific weights of less than 20 lb/kw (SNAP 8 is estimated to be 45 to 50 lb/kw), power conditioning specific weights of less than 5 lb/kw, and ion engine efficiencies of greater than 60% should be considered as early goals.

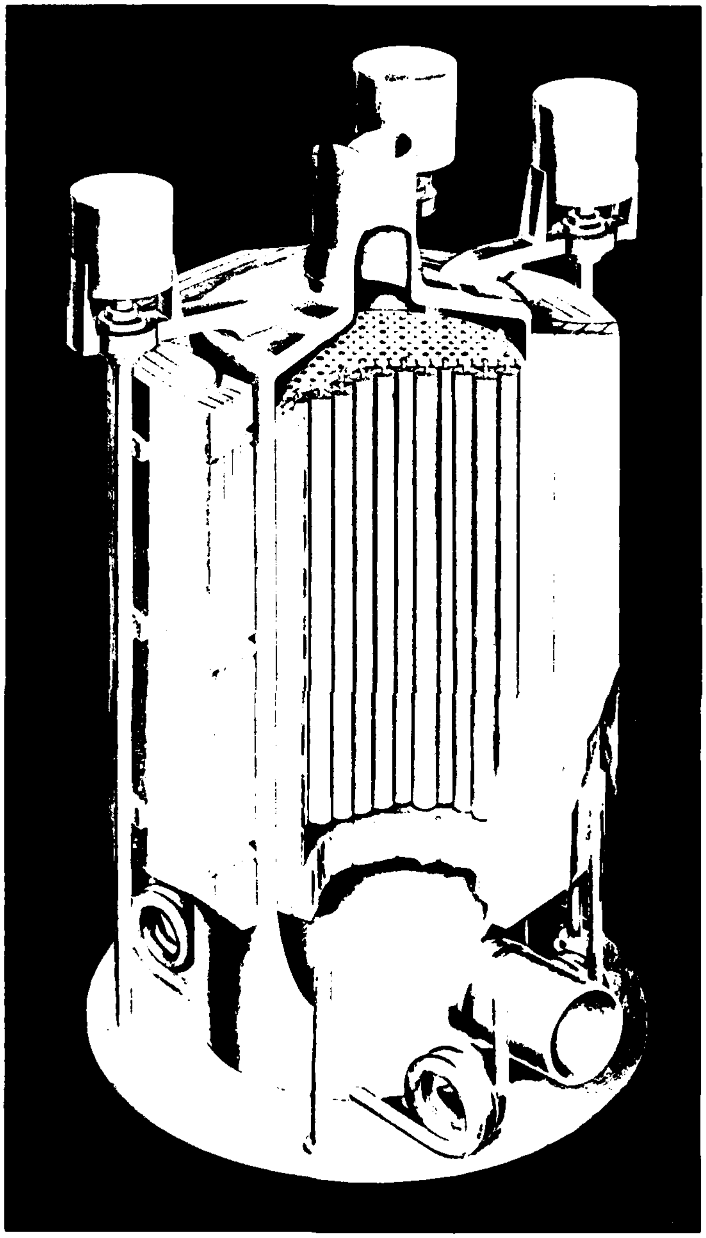

Fig. 1. SNAP-8 Reactor

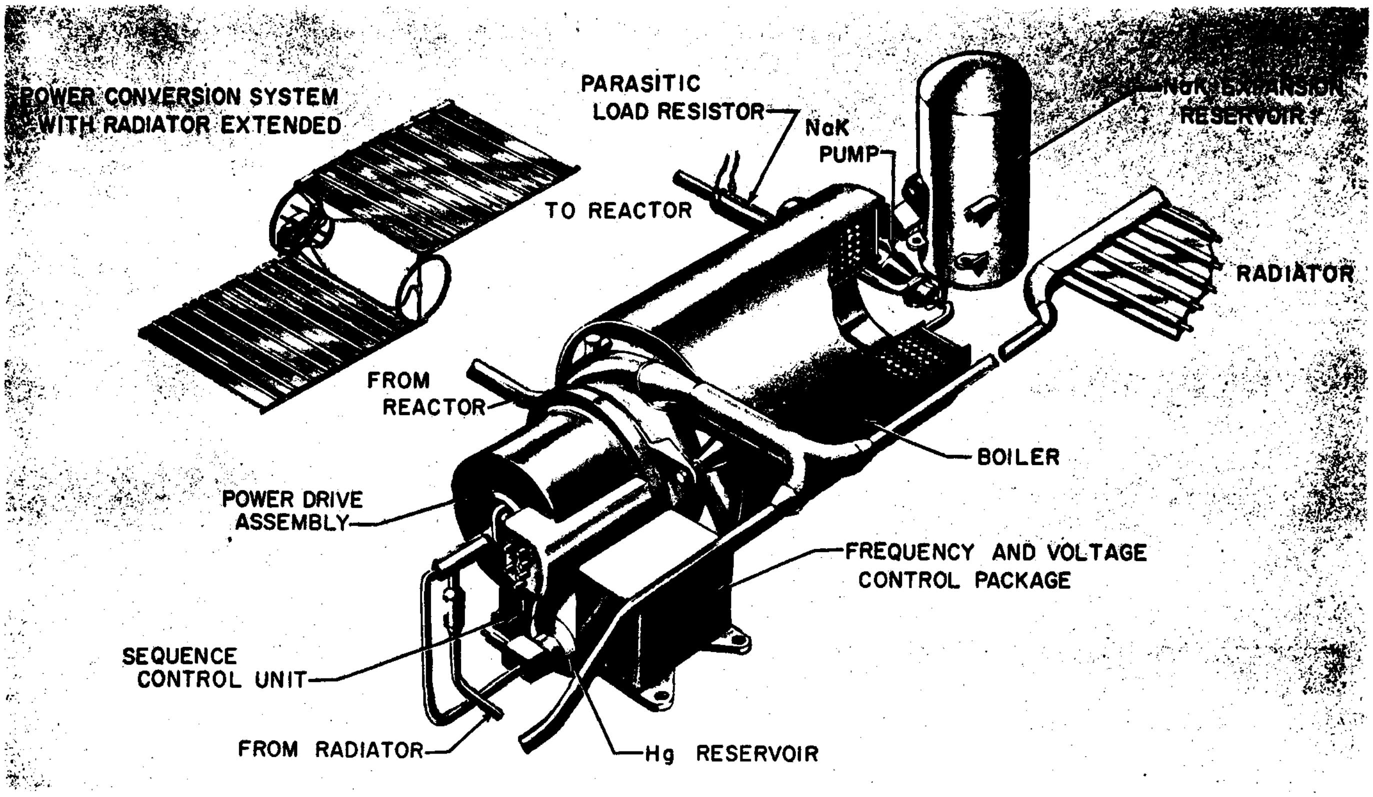

Fig. 2. SNAP-8 Power Conversion System

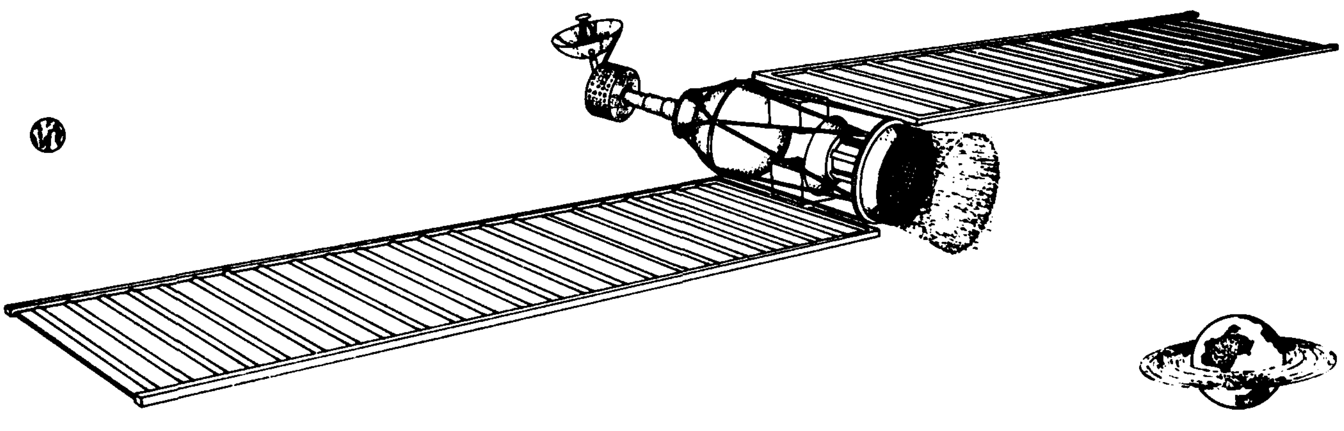

Fig. 3. Flat Panel Radiator Configuration

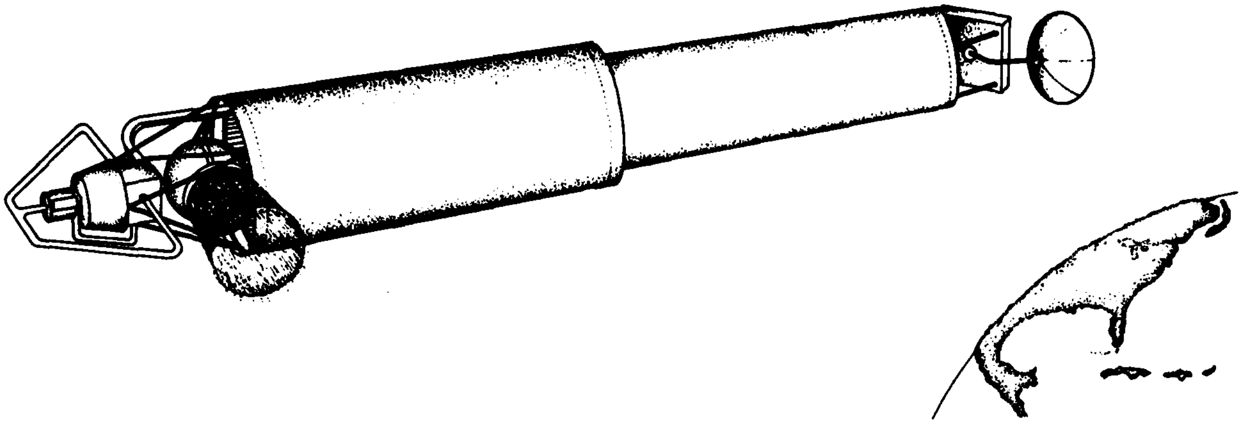

Fig. 4. Telescoping Radiator Configuration

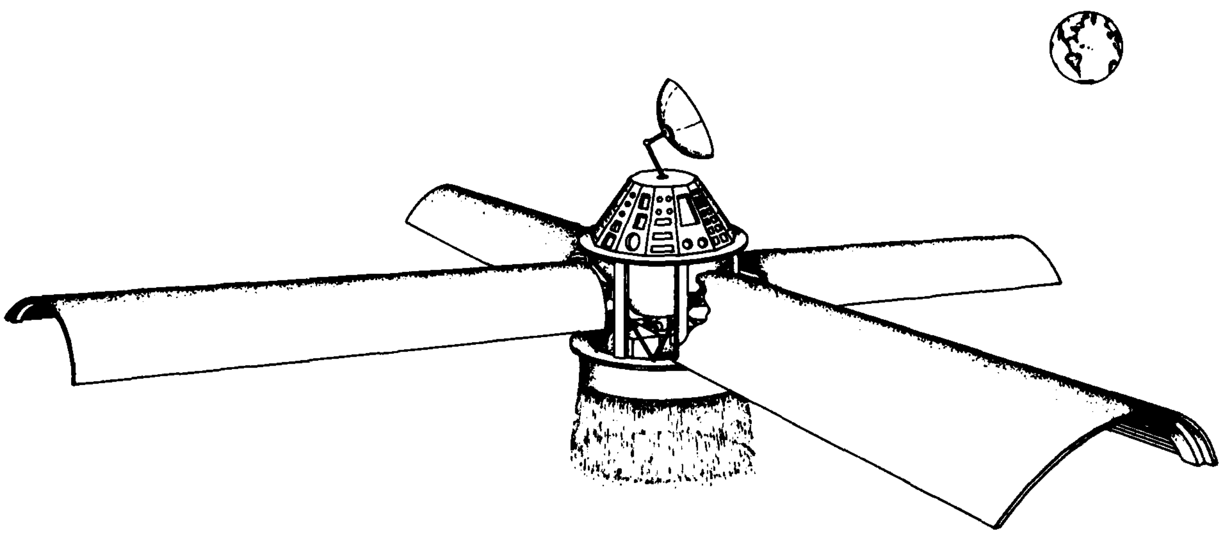

Fig. 5. Thimble Radiator Configuration

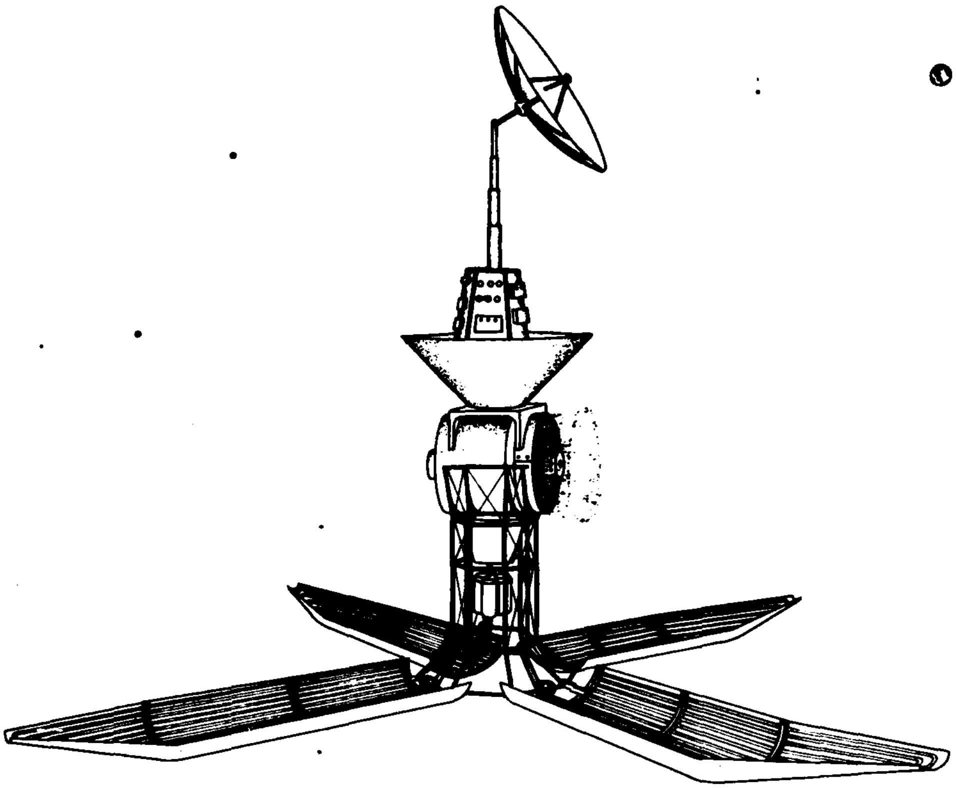

Fig. 6. Clamshell Shroud Radiator Configuration